



High Performance Metal Solutions

Refractory Metals for Thermal Management

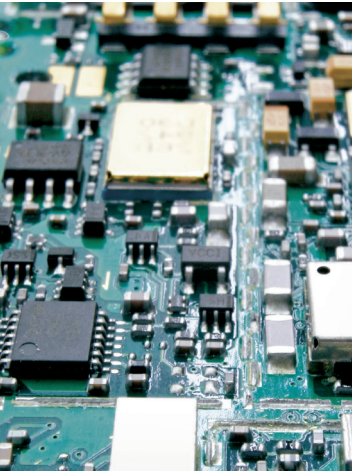
H.C.Starck 

High Performance Metal Solutions

Introducing H.C. Starck

H.C. Starck Solutions is a company with 300 employees in the United States. Our 2 ISO- certified production locations, research and laboratory facilities, and sales and business offices are located in the Midwest. We apply our engineering, technology, and industry expertise to develop custom solutions for our customers. We produce a unique assortment of refractory metals, including molybdenum, tungsten, tantalum, niobium, rhenium, and their alloys.

Introducing H.C. Starck	2
Materials – Development – Solutions	3
Materials:	
High Tech Materials for High Tech Solutions	4 – 5
Development:	
The Innovative Power of H.C. Starck	6
Solutions:	
Value-Added Product Solutions for Thermal Management Products	7
Pure Products	7
Laminate Products	8
Composite Products	9
Comparison of Product Properties	10 – 11



1

Materials ...

... stands for H.C. Starck Solutions providing a unique range of high performance materials that are unsurpassed in quality and supply reliability.

2

Development ...

... stands for our intensive R&D and application-oriented expertise, which makes us a driving force behind new products, technologies, applications and markets.

3

Solutions ...

... stands for the ability to support our customers along the entire value chain – from powder to finished components – with innovative and customized solutions.

Materials – Development – Solutions: Driving Your Value Creation

Our high tech materials and technologies, creatively combined with the innovative power of H.C. Starck Solutions, produce value-added solutions for thermal management applications.

| Materials |

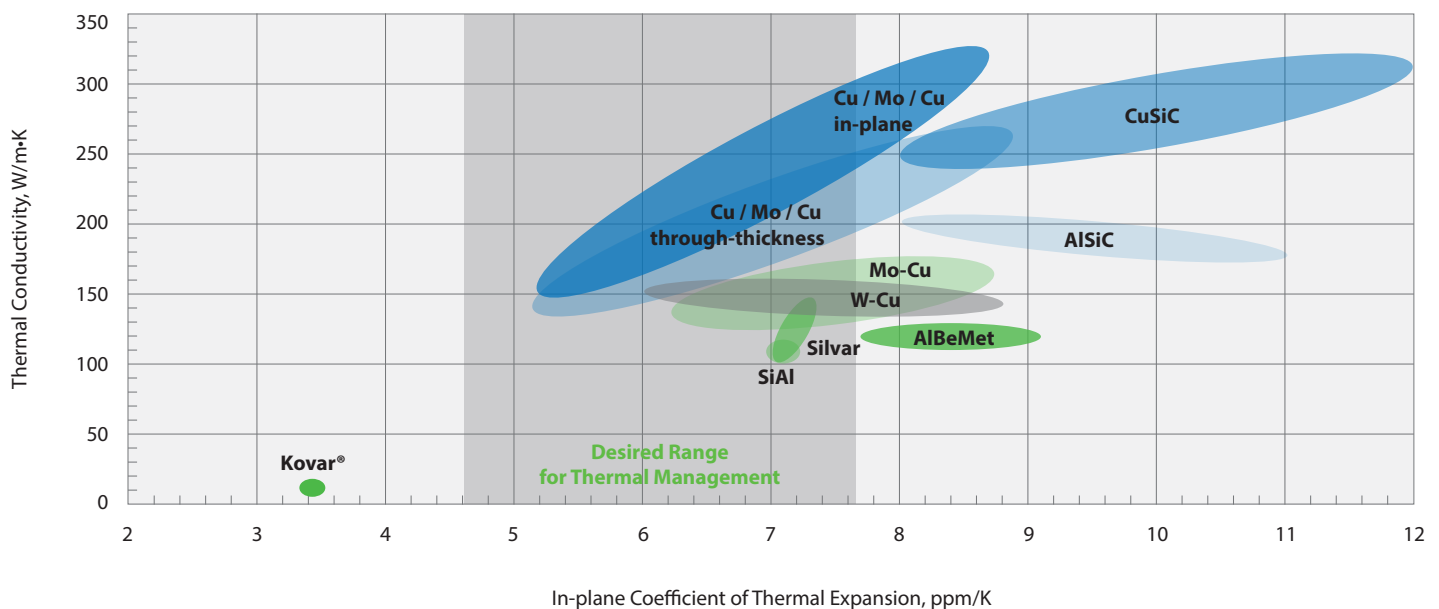
High Tech Materials for High Tech Applications

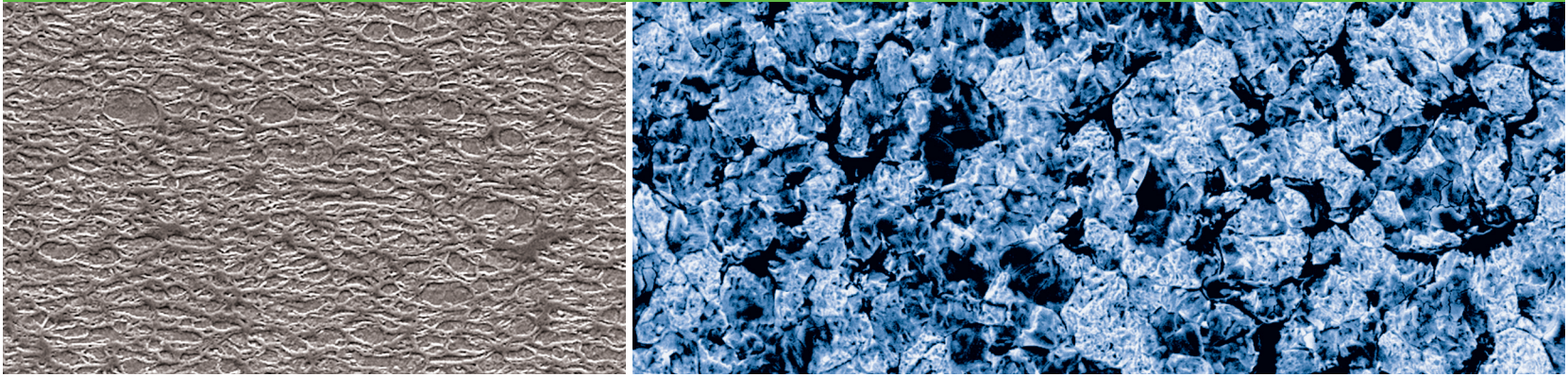
H.C. Starck Solutions has decades of experience in the production of high performance materials that provide solutions to demanding applications in the electronics industry.

Custom-engineered thermal management materials from the Fabricated Products Group of H.C. Starck Solutions are helping the electronics industry continue its rapid growth, part of which is driven by increasing miniaturization. This trend puts ever greater cooling demands on electronic circuitry. Our molybdenum and tungsten materials, laminates, and engineered composite materials are uniquely suited for these applications.

The thermal management properties of our materials include low and controlled CTE (coefficient of thermal expansion) and high TC (thermal conductivity), which help remove heat rapidly from high power density devices. Equally important is the expertise of our engineering staff in designing highly engineered materials that match the specific requirements of each application.

Our Cu / Mo / Cu laminates have an adjustable CTE that could be matched to various semiconductor substrates while maintaining high thermal conductivity, which makes them an ideal choice for power devices where considerable heat is generated.





Exceptional Properties:

- > **Adjustable CTE and TC values**
- > **Suitable for Si-based devices**
- > **Low electrical and thermal resistance**
- > **Moderate thermal conductivity**
(Mo = 140-150 W/m•k)
- > **Suitable for large area power devices with considerable heat generation**

Some of the critical parameters in selecting a heat spreader material are its thermal conductivity and the CTE-mismatch for a given die. These two parameters could be quantified by introducing a Thermal Compatibility Factor for a given heat spreader – die pair in a simple equation:

$$\lambda \text{ (Heat Spreader)} / \Delta \text{ CTE (Die – Heat Spreader)}.$$

The resulting ratio could be used to evaluate the compatibility of a heat spreader material with a given die. A high compatibility factor results from a high thermal conductivity value, and a low CTE-mismatch. The figures in the table below provide information on thermally compatible typical die – heat spreader pairs. It clearly shows the advantages of refractory metal based products.

Thermal Compatibility Factors for Die – Heat Spreader Pairs

	GaAs	GaP	GaN	InP or AlN	SiC	Si
Cu	36	32	35	32	30	29
Al	13	12	13	12	11	11
Mo	227	353	318	265	114	88
Cu / Mo / Cu Laminate	2080	198	2080	173	104	87
Cu-Mo (85:15)	363	94	242	85	58	50
Kovar®	170	14	57	12	8	7
Cu-W (90:10)	533	110	320	100	67	57
AlSiC	91	60	83	57	47	43
Silvar	219	83	170	77	55	48
AlSi	16	14	16	14	13	12
AlBeMet	26	23	25	22	21	20
CuSiC	102	74	96	72	61	57
CVD Diamond	337	460	354	483	659	806
Al-Graphite	128	353	144	460	767	329

| Development |

The Innovative Power of H.C. Starck Solutions

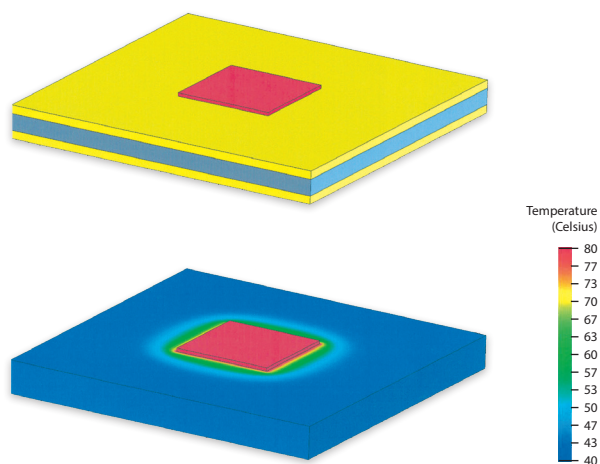
Innovation and research are key components at H.C. Starck Solutions. As a worldwide leader in refractory metals, we have state-of-the-art laboratories where we are constantly improving, refining and innovating our products and materials. H.C. Starck Solutions' R&D programs are shaped by a constant dialogue with our customers. By listening to their needs and requirements, we strive to develop new and innovative products for the future of the thermal management industry.

H.C. Starck Solutions develops and manufactures thermal management components for HB-LEDs (High Brightness LEDs) and laser diodes, such as Mo-Cu composites, Cu / Mo / Cu laminates, and plated molybdenum and tungsten flat products. The reliability and efficiency of semiconductor devices can be improved by maximizing the thermal conductivity of the heat dissipating components, while matching their coefficients of thermal expansion (CTE) to those of the substrates.

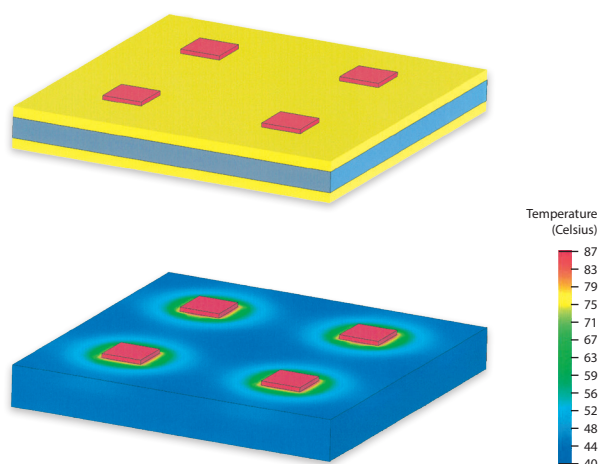
We use finite element modeling as a computational tool to develop customized products for special applications that require effective heat removal under extreme conditions. Our advanced modeling capability enables us to address the needs of our customers by optimizing our current products or developing new products in a timely manner.

Additional products under development provide enhanced thermal conductivity along the z-axis (through-thickness) and the unique capability to tailor excessive heat dissipation along localized hot spots, using a special, patent pending process developed by H.C. Starck Solutions.

Single device on Cu / Mo / Cu base plate



Four devices tightly placed on Cu / Mo / Cu base plate

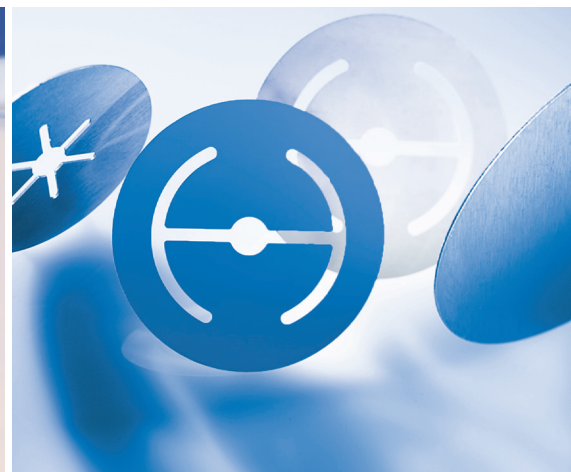
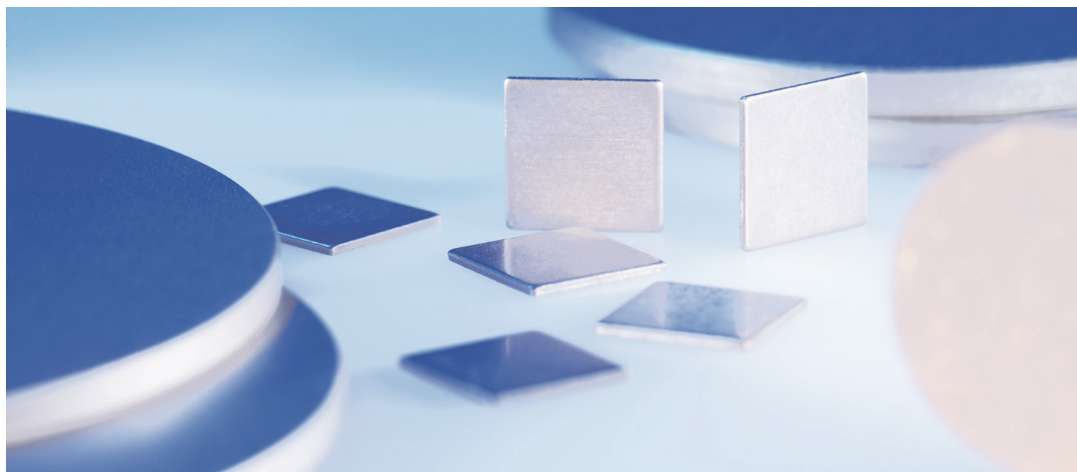


| Solutions |

Value-Added Solutions for Thermal Management Products

Many technological advancements in recent years require materials with characteristics that are not attainable as a monolithic system. In response, H.C. Starck Solutions has demonstrated a portfolio of products with unique capabilities by combining dissimilar materials by using a number of different engineering techniques.

These materials exhibit unique properties sought by design engineers for a wide variety of new applications such as electronic packaging, HB LEDs (High Brightness Light Emitting Diodes) for automotive headlamps and other applications, power semiconductors, and power controls for hybrid vehicles.



Pure Products

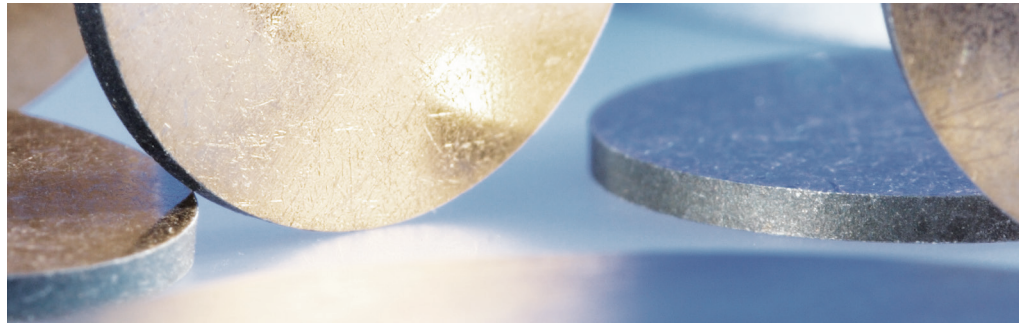
Molybdenum and tungsten discs and squares are widely used as contact materials in silicon controlled rectifier diodes, transistors and thyristors. Both materials have similar coefficients of thermal expansion (CTE) to silicon combined with moderate thermal conductivity, and are therefore suitable for large area power devices where considerable heat is generated. Further applications include the use of molybdenum and tungsten as heat sink bases in IC's, LSI's and hybrid circuits.

Benefits:

- > **CTE matched to semiconductor substrate**
- > **Good thermal conductivity**
- > **High volume production**
- > **Proven in high value applications**

Laminate Products

H.C. Starck has pioneered the development of two clad material systems, all of which use molybdenum as the primary constituent of the laminate. The major advantages of these structures are suitable Coefficient of Thermal Expansion (CTE), good thermal conductivity, high mechanical rigidity, corrosion resistance and superior adhesion characteristics when joining parts together.



Benefits:

- > **CTE matched to semiconductor substrate**
- > **Excellent thermal conductivity**
- > **High volume production**
- > **Proven in high value applications**
- > **Approved for military and aerospace applications**

Copper / Molybdenum / Copper Laminates

The copper constituent in the Cu / Mo / Cu laminate significantly enhances thermal conductivity and enables a design engineer to choose a CTE that matches other critical electronic materials such as silicon, aluminum nitride, gallium arsenide, Kovar®, alumina and beryllia.

Nickel / Molybdenum / Nickel Laminates

These Ni / Mo / Ni laminates are differentiated from the Cu / Mo / Cu laminates when used in higher temperature processing, such as brazing, where superior adhesion characteristics are required.

Composite Products

Advancements in electronic controls in high power equipment have resulted in specific demands on the packaging materials. Molybdenum and metal-metal matrix composites materials manufactured by H.C. Starck minimize stress in the package while allowing the electronics to operate in the manner desired.



Tungsten-Copper Composites

Tungsten-copper is a composite material that maintains the excellent performance of tungsten and copper, such as low heat resistance, excellent thermal and electrical conductivity. It can easily be machined into the required shape and finish. By using a tungsten skeleton and infiltrating it with copper, near-net-shape and relatively large pieces with different ratios of tungsten and copper can be produced. There are two standard ratios available in the W-Cu composite line:

70% Tungsten: 30% Copper | 90% Tungsten: 10% Copper

Molybdenum-Copper Composites

Molybdenum-copper is a composite material. It has similar thermal properties to the tungsten-copper composite, but its lower density makes it more suitable for applications where weight limitations are a factor.

Using a molybdenum skeleton and infiltrating it with copper, a variety of Mo:Cu ratios can be created to match the performance requirements of the application. The standard ratio is:

70% Molybdenum: 30% Copper

Mo-Cu composite is available in the following forms:

Sheet material | Coils | Small parts in near net shape

Benefits:

- > **Excellent thermal conductivity**
- > **CTE matching to semiconductor substrate**
- > **Ratio of molybdenum or tungsten to copper can be adjusted to modify thermal properties**
- > **Proven in high value applications**
- > **Approved for military and aerospace applications**

Comparison of Thermal Products

Product	Parameters	Applications
Pure Molybdenum Pure Tungsten	<ul style="list-style-type: none"> > CTE match with semiconductor substrates and ceramics > Stable CTE (-55°C through 900°C) > Moderate Thermal Conductivity (see table on page 10) > Compatible with plating processes > Can be laser, wire or punched to design 	<ul style="list-style-type: none"> > Power semiconductor > Wear plates > Heat spreaders / Heat sinks
Copper Moly Copper Clad	<ul style="list-style-type: none"> > CTE match with semiconductor substrates and ceramics > Stable CTE (-55°C through 900°C) > High Thermal Conductivity (see table on page 10) > Good Surface adhesion characteristics – solder > Compatible with plating processes > Lightweight 	<ul style="list-style-type: none"> > HB-LEDs > Lids / Covers > Multi-Chip Modules > Military Defense Applications – Radar / Aerospace > Heat spreaders / Heat sinks > IC packaging
Nickel Moly Nickel Clad	<ul style="list-style-type: none"> > CTE match with semiconductor substrates and ceramics > Stable CTE (-55°C through 900°C) > High Thermal Conductivity (see table on page 10) > Good Surface adhesion characteristics for brazing applications > Compatible with plating processes > Lightweight 	<ul style="list-style-type: none"> > HB-LEDs > Lids / Covers > Multi-Chip Modules > Military Defense Applications – Radar / Aerospace > Heat spreaders / Heat sinks > IC packaging
Molybdenum-Copper Composite	<ul style="list-style-type: none"> > CTE of 6.8~10.5 ppm/K > High Thermal Conductivity (see table on page 10) > Can be stamped or EDM cut > Can be plated with Nickel & Gold or other metals > Lightweight > Good machinability 	<ul style="list-style-type: none"> > HB-LEDs > Lids / Covers > Multi-Chip Modules > Military Defense Applications – Radar / Aerospace > Heat spreaders / Heat sinks > IC packaging
Tungsten-Copper Composite	<ul style="list-style-type: none"> > CTE of 6.5~9.6 ppm/K > High Thermal Conductivity (see table on page 10) > Can be stamped or EDM cut > Can be plated with Nickel & Gold or other metals > Good machinability 	<ul style="list-style-type: none"> > HB-LEDs > Lids / Covers > Multi-Chip Modules > Military Defense Applications – Radar / Aerospace > Heat spreaders / Heat sinks > IC packaging

Available Thickness and Formats

Product	Thickness	Sheet Width	Sheet Length	Coil
Pure Molybdenum Copper Moly Copper Clad Nickel Moly Nickel Clad (same properties)	0.001 to 0.005 in. (0.0254 to 0.127 mm) 0.005 to 0.100 in. (0.127 to 2.54 mm) Up to 0.250 in. (6.35 mm)	12 in. max (304.8 mm) 24 in. max (609.6 mm) 24 in. (609.6 mm)	Up to 35 ft. (10.66 m) depending upon thickness Up to 35 ft. (10.66 m) depending upon thickness 8 ft. (2.44 m)	Up to 35 ft. (10.66 m)
Molybdenum-Copper Composite	0.001 to 0.005 in. (0.0254 to 0.127 mm) 0.005 to 0.100 in. (0.127 to 2.54 mm) Up to 0.250 in. (6.35 mm)	12 in. max (304.8 mm)	Up to 55 in. (1.4 m)	Up to 55 in. (1.4 m)
Tungsten-Copper Composite	in near-net shapes	in near-net shapes	in near-net shapes	in near-net shapes

USA

H.C. Starck Solutions Euclid, LLC

21801 Tungsten Road
Euclid, OH 44117-1117 USA
T +1 216 692 3990
F +1 216 692 0029

H.C. Starck Solutions

199 Wells Ave #107
Newton, MA 02459 USA
T +1 617 630 5800
F +1 617 630 5879

H.C. Starck Solutions Coldwater, LLC

460 Jay Street
Coldwater, MI 49036 USA
T +1 517 279 9511
F +1 517 269 9512

Japan

H.C. Starck Fabricated Products GK

3F Shiodome Building,
1-2-20 Kaigan,
Minato-ku, Tokyo
105-0022 JAPAN
T +81-3-6721-8177
F +81-3-6733-8896

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info@hcstarcksolutions.com
www.hcstarcksolutions.com

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